United States Navy Advanced Crew Station Evaluation Techniques

Jennifer Crawford
Industrial Engineer
Crew Systems Division
Naval Air Warfare Center - Aircraft Division
Patuxent River, MD 20670

ABSTRACT

The United States Navy is tasked to perform a baseline accommodation assessment of in-service Navy and Marine. The requirement to advance the technical processes used in defining the interior confines of crew stations for the purpose of assessing accommodation issues is included in the program task.

A new methodology has been developed by the United States Navy that utilizes advanced data collection technology and data analysis techniques. This set of procedures is called the Navy Advanced Crew Station Evaluation Technique (NACSET) which can be applied to any crew or work station. The evaluation investigates accommodation issues such as head, leg, and knee clearance, eye position, and reach ability.

The analysis produces accommodation prediction equations for each issue under investigation. The prediction equations are used to develop three products: Percent Accommodated, the Individual Screening Process, and Anthropometric Restriction Codes for the USN and USMC. NACSET provides methods for not only evaluating current crew stations, but also crew stations currently under design. NACSET methods are also easily adaptable to fit a program's specific needs.

INTRODUCTION

The United States Navy is tasked to perform accommodation assessments of in-service Navy and Marine aircraft (reference 1). The purpose of the sponsored program focuses on reengineering issues for increased accommodation provisions. Included in the program tasks is the requirement to advance the technical processes used in defining the interior confines of crew stations, and then evaluate the crew stations to determine the level of accommodation with respect to human anthropometric dimensions.

The Aircrew Anthropometric Accommodation Assessment (AAAA) methods outlined in reference 2 were originally designated for use in the program approach. The specified methods include instructions on subject selection, subject measurement, anthropometric assessment procedures, and data interpretation. The AAAA methods determine a Rough Order of Magnitude threshold for a given anthropometric variable and cockpit interface.

The AAAA methodology has become outdated due to the fact that advances in technology can increase the accuracy, reliability, and efficiency of data collection. The older methods also do not account for the interaction of all variables of accommodation; instead they investigate each area independently. Preservation of crew station data is not effective or reliable for future references because the methodology designated for collection has no measurable accuracy ratings. Test subject evaluation also faces the same problems using the AAAA methods.

In response to these shortcomings, the Navy has developed procedures that utilize advanced data collection technology and data analysis techniques. Additional procedures also allow data to be collected in a laboratory setting, which the previous methods could not address. The new Navy Advanced Crew Station Evaluation Technique (NACSET) makes data collection and analysis more efficient with a degree of accuracy that can be quantitatively measured.

SCOPE OF TESTS

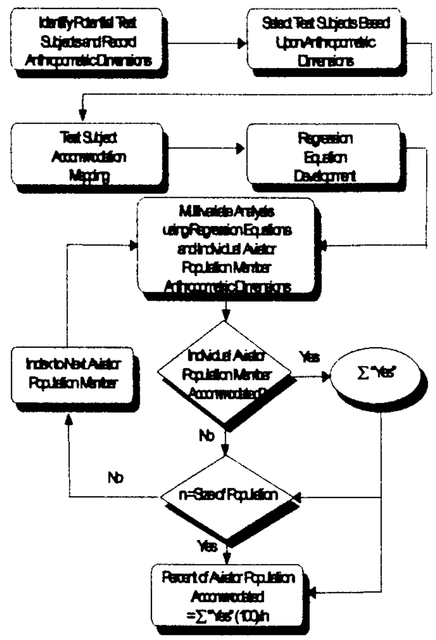
The new methodology, Navy Advanced Crew Station Evaluation Technique (NACSET) has been developed over a period of three years. It has been refined, practiced, and improved upon during evaluations conducted on aircraft and in laboratory settings. The AAAA methods were improved upon to meet current needs while completely new methods of evaluation were developed to keep up with the technology utilized. During this learning and development process specialized training was required as well as a capital investment to upgrade existing equipment and facilities.

NACSET addresses all aspects of evaluating a crew station in a static environment. These methods do not take into account limitations due to strength or the effects of flying aggressive flight profiles. NACSET is not limited to just aircraft crew station analysis. The techniques may be applied to any type of work station across every service and in the commercial world.

METHOD

A flowchart summarizing the accommodation evaluation techniques outlined in NACSET is shown below in Figure 1.

Figure 1



SUBJECT IDENTIFICATION AND SELECTION

Initial subject identification involves targeting people who are willing to assist in the accommodation evaluation of crew stations. It is helpful to identify a large population of potential subjects so when test subjects are required for an evaluation, a fairly large database from which to draw subjects will be readily available.

Once people have stated they are willing to be test subjects, their anthropometric measurements must be recorded. Anthropometric measurements are dimensions of the human body, and a variety of these measurements are taken that may be useful in determining the accommodation levels of crew stations. The measurements are illustrated below in Figure 2.

Figure 2

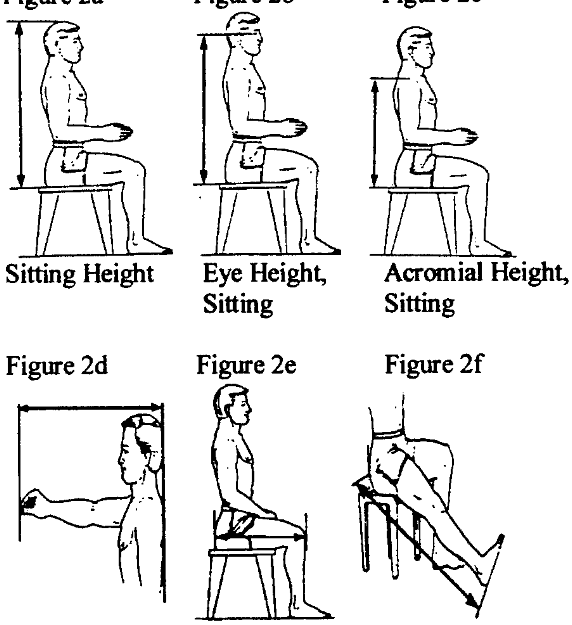


Figure 2a Sitting Height

Figure 2b Eye Height, Sitting

Figure 2c Acromial Height, Sitting

Figure 2d Thumb Tip Reach

Figure 2e Buttock-Knee Length

Figure 2f Functional Leg Length

ANTHROTECH (formerly Anthropology Research Project, Inc.) of Yellow Springs, Ohio provides training on the proper techniques of anthropometric measurement. These are the same techniques employed in the 1988 Anthropometric Survey of Army Personnel (reference 3).

Subjects are selected for accommodation evaluation tests from the database by comparing their anthropometric measurements to the anticipated population that will be accommodated in the crew station under evaluation. The test subjects who are selected should extend slightly above and below the range of the anthropometric measurements of this population. NACSET uses the seven Joint Primary Aircraft Trainer System (JPATS) commonly used in a crew station evaluation

cases listed in Figure 3 for evaluation of Navy and Marine crew stations. The anthropometric dimensions of these cases were derived from the 1988 Anthropometric Survey of Army Personnel by a Department of Defense joint working group. The JPATS cases represent the current expanded population in terms of combinations of anthropometric dimensions that will be accommodated by future joint military aircraft. Thirty test subjects are desirable when conducting an accommodation evaluation, but as few as ten subjects have been used due to asset and time limitations. Ten subjects are acceptable as long as their anthropometric measurements cover the range of the population to which the crew station is being tested.

Figure 3

Joint Primary Aircraft Training System (JPATS) Anthropometric Cases

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Thumb Tip Reach	27.0	27.6	33.9	29.7	35.6	36.0	26.1
Buttock-Knee Length	21.3	21.3	26.5	22.7	27.4	27.9	20.8
Knee Height-Sitting	18.7	19.1	23.3	20.6	24.7	24.8	18.1
Sitting Height	32.8	35.5	34.9	38.5	40.0	38.0	31.0
Eye Height-Sitting	28.0	30.7	30.2	33.4	35.0	32.9	26.8
Shoulder Height-Sitting	20.6	22.7	22.6	25.2	26.9	25.0	19.5

CREW STATION GEOMETRY

Before the evaluation takes place, the crew station must be examined to ensure that the test will account for all accommodation concerns. A background survey is conducted to determine potential accommodation issues in the crew station. Next, operation critical and emergency controls are identified, possible head, leg, and knee obstructions are noted, past lessons learned are reviewed, and operationally acceptable test protocol and evaluation criteria is established.

After the evaluation test plans are complete, hard copy drawings of the crew station are obtained to identify the location of controls and clearance obstructions. Blue print diagrams detailing the crew station's coordinate system are also examined. These various data are used to establish a CAD drawing of an existing crew station.

The creation of the crew station CAD drawing utilizes the FaroArm™, a coordinate measurement machine. The FaroArm™ takes data such as points, lines, and planes in a three-dimensional coordinate system, and places these features in an AutoCAD® drawing via AnthroCAM™, the software that interfaces AutoCAD® and the FaroArm™. All prescribed hand operated controls, pedals, ejection path obstructions (when applicable), overhead obstructions, and leg clearance obstructions are digitized into the CAD file. In addition, any other features of the crew station identified as accommodation issues during the background survey are digitized with the FaroArm™.

The FaroArm™ is taken to the existing crew station at which time the geometry is collected for use in the accommodation evaluation. However, a CAD drawing from the manufacturer is an acceptable substitute for a crew station under certain situations. The manufacturer's CAD drawings are used when the crew station has been designed (or redesigned) but not yet produced such as that of the US Army's RAH-66 Comanche seen in Figure 4. The RAH-66 Comanche is still under design, so crew station geometry can not be collected on a production aircraft. Therefore, the manufacturer's CAD drawings are suitable replacements for the crew station evaluation.

Figure 4

AutoCAD® image of the front and aft cockpits of the RAH-66 Comanche

Once crew station geometry has been collected with the FaroArm™, the AutoCAD® drawing is rendered. The process of rendering essentially transforms the collection of lines, planes, and points digitized by the FaroArm™ into a form that resembles the actual crew station. Rendering the geometry drawing provides confirmation that the proper features are being evaluated and aids in explanations of how the study was conducted after the test is complete. Illustrations of a non-rendered and rendered drawing of the AV-8B cockpit are shown below in Figures 5a and 5b, respectively. These images demonstrate the differences between the two forms that can be created by a single geometry drawing.

Figure 5

Figure 5a
Non-Rendered Drawing of AV-8B

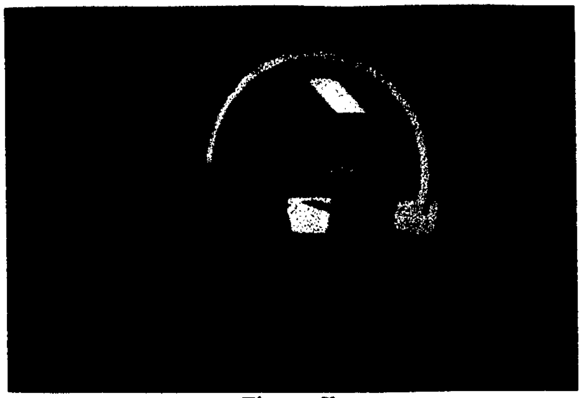


Figure 5b
Rendered Drawing of AV-8B

CREW STATION ACCOMMODATION EVALUATION

Each test subject is fitted in the appropriate gear for the crew station under evaluation. The list of appropriate gear for US Navy and Marine aircraft can be found in reference 4; however, if a crew station other than US Navy or US Marine Corps is being evaluated, refer to that service's or crew station's technical manual to determine proper gear configuration.

A specific AnthroCAM™ computer routine is developed for each crew station under evaluation. Data collection routines are custom-programmed using AnthroCAM™ software to ensure consistency of test conditions. Accommodation data are collected with the FaroArm™ on each test subject, and the routine ensures that the test remains consistent through all test subjects. The routine prompts the operator as to which data points are to be taken on each subject.

The routine is designed to evaluate each subject in multiple trials (one seat position per trial) covering the full range of available seat positions at set intervals. When the seat moves along two axes (horizontal and vertical travel), the evaluation is conducted at the four corners of movement. A one-axis seat (vertical or horizontal movement only) is placed in at least four positions along its path of travel.

Each subject is locked into the crew station's seat restraint system with an upright sitting posture and hips against the seat back. Each trial (seat position) is conducted at a specified fixed seat position, and four to five trials cover the full range of motion of the seat.

Accommodation data are collected at the crew station using the FaroArm™. An overview of the basic accommodation issues that are evaluated is presented below:

External Field Of View (EFOV):

Eye position is measured using the FaroArm™ to determine the actual eye location for each subject's sitting eye height. The location of the subject's outboard ectocanthus (corner of the eye) is measured and translated to the centerline plane of the seat for comparison with the design eye point. External Field of View is measured by comparing the design eye point (DEP) and the subject's eye position in the aircraft, and dimensioning the distance between the two points (reference 5).

Reach to Controls

Reach is evaluated with the shoulder harness locked in an aircraft setting (zone 2 reach, stretching against a locked restraint system). Reach to primary and time-critical emergency controls are zone 1 controls (locked restraint system and no arm or shoulder stretch); but for operational reasons zone 2 is often used as criteria to assess multivariate accommodation. Miss distance measurements, with shoulder harness locked, are made from a point on the hand that would contact the control/switch (while gripping as though to operate the control / switch) to the corresponding point on the control. Results specify the minimum thumb tip reach required to allow a person to reach, grasp, and operate each particular control (reference 6).

Reach to Pedals

Reach to pedals is only measured in those crew stations equipped with some type of pedal controls, such as rudder pedals. Pedal location is measured at the most forward adjustment position at which full control is possible for each subject. Measurements are taken with the subjects positioned in an upright sitting posture with hips back in the seat. Available pedal adjustment distance is calculated from the distance between the full aft position of the pedals and maximum forward functional leg reach (reference 6).

Head Clearance

Head clearance measurements are taken between the top of the head or helmet (head stationary and upright) and the overhead surface or canopy breakers on crew stations so equipped. Head clearance is evaluated by measuring the highest point on the subject's head or helmet. Clearance distance is calculated between this point and the overhead surface (reference 6).

Ejection Clearance (when applicable)

Ejection clearance is evaluated only if the possibility of ejection from the crew station exists. The subject's knee position is measured, and it is dimensioned to the outer edge of the ejection envelope or to any object that is considered an obstruction to the knees in the case of an ejection. Available knee clearance distance is calculated between the measured points (reference 6).

Leg Clearance

Leg clearance is evaluated by measuring a line on the front of the shin. The subject operates the pedals to determine the leg position that places the shin closest to the main instrument panel. Leg clearance distance from the instrument panel or other obstruction is measured during each trial (reference 6).

ALTERNATIVE LAB TESTS

Once crew station geometry has been collected, increased test efficiency can be achieved by performing the bulk of the subject testing in a laboratory setting. The benefits include decreased asset test utilization and increased test control. The option of performing the subject evaluation in a lab is available depending on whether a representative crew station seat can be found and brought to the lab setting.

A representative crew station seat is brought to the Accommodation Lab and installed in the Crew Accommodation and Geometry Evaluation Stand (CAGES) at the same angle (e.g., seat installation angle) as in the crew station. Detailed geometry is then taken of the lab seat and inserted on top of the crew station geometry drawing taken from the actual test asset at the same point of origin, creating a virtual crew station with the FaroArm™.

Subjects are brought to the lab and donned in the appropriate gear (reference 4). Each subject is locked into the seat using the restraint system, and the evaluation is performed. Targets are used to represent the location of each control used to evaluate reach. The subject is asked to reach towards these targets, and the FaroArm™ is used to digitize each reach. The FaroArm™ is also used to evaluate head, eye, and knee positions. In short, the evaluation is performed just as it would be at the crew station.

There are advantages of performing the subject evaluation in the lab:

- The lab setting is a more controlled environment where the team does not interrupt the normal day-to-day operations of the asset.
- More subjects can be evaluated because the team does not have to worry about transporting them to and from the crew station or coordinate multiple safety briefs for the subjects.
- The team is only working around the crew station seat instead of the entire crew station itself.
- The evaluations are easier to conduct, especially in the area of reach, because the subjects do not have to work within the confines of the crew station. They can reach as far as they want without worrying about the crew station obstructing reach.

Subjects should be evaluated at the actual crew station to validate the lab evaluation. The subjects should range in size to represent the extreme small and extreme large ends of the population that is under investigation. The subjects selected for the validation should differ from those used in the crew station evaluation to insure unbiased results.

The most significant program advantage is the ability to get into design issues early in the crew station's life. Aside from evaluating a current crew station in the lab for the benefits listed above, a future crew station or upgrade under design can also be evaluated. The only requirements to perform this evaluation on the new crew station is an AutoCAD® or CATIA® file of the crew station, and a seat that closely resembles the one which will be used in the new crew station. The FaroArm™ can interface with the crew station file, and the evaluation is performed using the laboratory methods discussed.

DATA ANALYSIS

Data points are organized into a Microsoft Excel® Workbook. These data points are segregated into respective worksheets. Separate sets of data correspond to a specific area of the crew station that is being evaluated. A unique set of data exists for eye position, functional reach to controls, functional leg reach, overhead clearance, leg clearance, and ejection clearance (if applicable).

Multiple regression analysis is performed on each data set. The general purpose of this is to determine the relationship between several independent (predictor) variables and a dependent (criterion) variable. Data points are assigned as either independent or dependent variables. The dependent variable is the miss or hit distance in each seat position pertaining to the accommodation issue under evaluation. The independent variables are the anthropometric measurements relating to the issue under evaluation, and the seat position at which each measurement is taken. For example, when evaluating eye position, the dependent variable is the distance the subject's eyes are above or below the design eye point, and the independent variables are the subject's sitting eye height and the seat positions at which the measurements are taken.

Outlier analysis is performed with the help of the statistical software program Statistica®; outliers are identified and discarded, and the process continues until no additional outliers are uncovered. Outliers are identified through various techniques:

- Hat Matrix Analysis-identifies outliers only in the independent variables
- Studentized Deleted Residuals-identifies outliers in the dependent variable

- Cook's Distance - overall measure of the combined impact of each case on all estimated regression coefficients
- DFFITS Test - determines if an outlying case is influential to the fitted values in the regression function

Once an outlier has been identified, it must be examined to determine if it should be discarded. An outlier identifies a case that is greatly affecting the regression function, but it does not always mean that it is a bad data point that should be discarded. Once all outliers have been identified, the regression analysis is complete.

Accommodation prediction equations are the final results of regression analysis. A set of equations are produced that cover six areas of crew station accommodation: eye position, functional reach to controls, functional leg reach, overhead clearance, leg clearance, and ejection clearance (if applicable). The equations predict accommodation in the crew station by using a subject's anthropometric measurements.

PRODUCTS

AIR 4.6 uses the accommodation prediction equations to develop three final products. The equations determine the percent of the given population accommodated in the crew station, provide an individual screening process for possible users of the crew station, and aid in the development of Anthropometric Restriction Codes (ARC's). The Chief of Naval Air Training (CNATRA) currently uses ARC's, and they can be found in references 7 and 8.

PERCENT ACCOMMODATED

A population consisting of a large number of subjects can be evaluated with the accommodation prediction equations to determine how many out of that population will be accommodated in the crew station. Each subject in the population must meet all anthropometric requirements simultaneously (Sitting Height, Sitting Eye Height, Functional Leg Length, Buttock-Knee Length, and Thumb Tip Reach). Once every case in the population has been processed through the equations, a percentage detailing how many were accommodated is produced. This is helpful when the population samples represent the actual population the crew stations are aimed at accommodating.

INDIVIDUAL SCREENING PROCESS

The individual screening process offers a multivariate approach in determining if a candidate will be accommodated in the crew station. The process investigates each interaction between the accommodation issues to determine if the candidate is truly accommodated. The results detail if the crew station will accommodate the candidate by offering a range of seat positions in which the candidate will be fully accommodated. If at least one seat position is not available, then the candidate will not be accommodated in the crew station.

The accommodation prediction equations screen individuals who may become a user of the crew station being evaluated. Once the anthropometric measurements are taken on a candidate, those measurements are entered into the equations. The results return by indicating if at least one seat position is or is not available. For example, the process may reveal that a candidate may have to position the crew station's seat to its maximum height in able to obtain the appropriate vision requirements. However, the process also indicates that the candidate is not be able to reach specified controls once the seat is moved more than halfway above its minimum position. The individual screening process with the use of computer software will return the statement that the candidate is not accommodated because a common seat position is not available in which all accommodation issues are satisfied.

The screening process is a very valuable tool when there are several different crew stations to which a candidate may be assigned (e.g., a Naval Aviator Candidate whose career path can follow a jet or helicopter pipeline). Accommodation prediction equations may be developed for a number of different crew stations and then arranged in a software program that will offer predictions on all crew stations at once for each candidate.

ANTHROPOMETRIC RESTRICTION CODES

Anthropometric Restriction Codes (ARC's) may be used to screen potential candidates in lieu of a screening software program. ARC's are constructed using the accommodation prediction equations to determine the minimum or maximum anthropometric dimension required for each anthropometric issue identified in the crew station. Four sets of ARC's representing ranges of specific anthropometric measurements exist for each crew station. These anthropometric measurements are Sitting Height, Functional Leg Length, Thumb Tip Reach, and Buttock-Knee Length. The ranges of measurements are assigned a code number from 0 to 9. Presently, a Sitting Height Code 0 represents a sitting height measurement between 32.0 and 32.4 inches (references 7 and 8).

Anthropometric measurements are taken on each candidate, and the sitting height, thumb tip reach, buttock-knee length, and functional leg length measurements are assigned a code from anywhere between 0 and 9. These codes are then compared to the crew station's restricted, fit-check, and accommodated codes.

The ARC's for a crew station specify what codes should be restricted from operation of the crew station and what codes are cleared for accommodation. For example, a Sitting Height Code 1 may indicate that this sitting height is restricted from operating a specified crew station. Therefore, any potential candidate whose sitting height falls into the Code 1 category is restricted from occupying the crew station.

CONCLUSION

The Navy Advanced Crew Station Evaluation Techniques (NACSET) have been developed and refined over a period of three years. NACSET can be incorporated or modified to perform accommodation evaluations of any type of crew station, and it can be used during various stages of a crew station's life. The methods are easily adaptable to conform to any type of project and its goals. The results produced take the forms of an Individual Screening Process, Anthropometric Restriction Codes, and determination of a Population Percent Accommodated. These products are helpful not only in the evaluation of current crew stations, but also those that are presently under design.

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BIOGRAPHY

Jennifer J. Crawford, AIR 4.6, Cockpit Accommodation Specialist, provides support to the Aircrew Accommodation Expansion Program and other platform specific projects. She has been a member of this team for three years performing duties such as test coordination and preparation, and data collection and analysis on anthropometric assessments of US Navy and Marine cockpits. She is certified to operate the FaroArm™, a coordinate measurement machine, and is also certified to take anthropometric measurements on humans. She has also recently been selected as a US Navy representative to the Air Standardization Coordinating Committee (ASCC) for Aerospace Medicine, Life Support, and Aircrew Systems (Working Party 61-Project Group 105). Ms. Crawford received her Bachelor of Science in Industrial Engineering from West Virginia University, and is currently pursuing a Master of Science in Engineering Management from Florida Institute of Technology.

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The U.S. Navy is tasked to perform a baseline accommodation assessment of in-service Navy and Marine. The requirement to advance the technical processes used in defining the interior confines of crew stations for the purpose of assessing accommodation issues is included in the program task. A new methodology has been developed by the U.S. Navy that utilizes advanced data collection technology and data analysis techniques. This set of procedures is called the Navy Advanced Crew Station Evaluation Technique (NACSET) which can be applied to any crew or work station. The evaluation investigates accommodation issues such as head, leg, and knee clearance, eye position, and reach ability. The analysis produces accommodation prediction equations for each issue under investigation. The prediction equations are used to develop three products: Percent Accommodated, the Individual Screening Process, and Anthropometric Restriction Codes for the USN and USMC. NACSET provides methods for not only evaluating current crew stations, but also crew stations currently under design. NACSET methods are also easily adaptable to fit a program's specific needs.

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